**Land-Use and Land-Cover Change: Decadal-Scale Dynamics of Carbon Storage Patterns as a Function of Land Ownership in the Southeastern Lower Coastal Plain Region of the U.S.**

Second Annual Progress Report

As Part of the NASA Program:

**NRA 99-OES-06**


Principal Investigators:

Michael W. Binford[1] (Department of Geography), Principal Investigator;
mbinford@geog.ufl.edu

Co-Investigators:
Grenville Barnes[1] (Department of Civil Engineering); gbarn@ce.ufl.edu
Henry L. Gholz[1,2] (School of Forest Resources and Conservation); hgholz@nsf.gov
Scot E. Smith[1] (Department of Civil Engineering); ses@ce.ufl.edu

[1]University of Florida, Gainesville, FL 32611
[2]National Science Foundation, 4201 Wilson Boulevard, Arlington, Virginia 22230


Project URL: http://www.surv.ufl.edu/nasa/

**Report Date: 10 April 2002**

ABSTRACT

We are studying how climate variability and land ownership influences carbon storage dynamics in forested ecosystems in the southeastern United States. Our time extent is from A.D. 1975 to 2000. The questions for this project are "How much carbon has been lost or gained from the SE forests as a consequence of climate variation and ownership patterns?" and "How can we model future changes in carbon storage if we know how ownership will change?" Our focus is on non-public (private industrial, private non-industrial) lands in the region. Four small (15 km x 15 km) sample areas were selected in year 1 for intensive study to determine the spatial and temporal patterns of changing land ownership and changing carbon storage over the 25-year period covered by data available from the Landsat program. Digital maps of land ownership compiled and mapped from local-government records for the year 2000 were completed in year 2 of the project, and historical maps at 2 to 5-year intervals are being inferred (property appraisers keep no historical maps, and we have developed a method for inferring previous parcels). The database model is described, as is the method for inferring land transfers in historical time. Carbon storage is being measured with remote sensing methods calibrated by on-the-ground measurements in an ecosystem that has been under intense study for nearly 20 years. This project is partially funding biomass (C) and net ecosystem exchange (NEE) measurements in a natural-regeneration stand of upland pine forest. Weather records from several stations within the study area define climate variability, and we will use the weather records to 1) examine relationships between landscape-wide carbon content changes and climate variation; and 2) model C uptake and biomass change with models that use meteorological variables as inputs. Salient accomplishments include the development of a general database model for tracking ownership, ownership type, and spatial extent of parcels over time, the development of a land-cover classification system that can be linked to biomass/carbon data reported in the literature, the development of a literature database of biomass and carbon content of the major forests of the S.E. U.S. coastal plain, NEE measurements of the natural regrowth stand, which represents ~20% of the upland forests of Florida, the acquisition and processing of over half of the cloud-free Landsat data for the study area from 1975 to 2000, and the nearly finished development of statistical models of the relationships between Landsat data and biomass/C storage. The delay of approvals for year 2 acquisitions of Landsat data is the only major issue slowing progress. We anticipate finishing the time-series land-ownership maps, and two alternative approaches to C storage maps, early in the third year of the study. Final analysis will be conducted in the middle of year three, and we anticipate writing a number of papers for submission to peer-reviewed journals.

Key Words: 1) Research Fields: Anthropogenic Effects, Carbon Cycle, Change Detection, Flux Towers, Historical Land Use, NPP GPP; 2) Geographic Area/Biome: Southeastern U.S. Coastal Plain, Florida, Temperate Forest; 3) Remote Sensing: Landsat; 4) Methods/Scales: Flux Towers, Land-cover Classification, Regional

INTRODUCTION – Questions, Goals, Approaches

The key elements of the research are to describe land cover/land-use change over the past quarter century in our study area, to estimate how much carbon storage has been affected by the observed changes, and to relate the kinds of changes to land ownership and, in the future, management practices. These elements address the first two of the NASA ESE questions explicitly: a) what are the changes in land cover and/or land use (monitoring/mapping activities), b) what are the causes of LCLUC? The answers will be useful for addressing the third NASA ESE question: c) what are the consequences of LCLUC?

Our focus is on non-public (private industrial and non-industrial) lands in the region, because these lands represent more than 85% of the region's area (NRC 1997), and because Federal and State lands in the region are managed with priorities that are not necessarily related to those of the region itself.

The substantive attention to social science in this project is about 50%, while the work load is about 35% social science, 35% flux tower and other carbon measurements, and 30% remote sensing mapping of forest cover and estimations of carbon cycle components. Our basic questions are how land ownership patterns change over time, and how those changes affect carbon storage as estimated by satellite remote sensing methods calibrated by on-the-ground measurements in a spatial subset of the study area. The thematic proportional coverage is 50% Carbon, 50% GOFC.

To review the choice of study sites, the selected 15 x 15 km study areas are shown in Figure 1 (reprinted from the Year 1 report). The selection method was described in last year's report. Details can be seen at the project website (http://www.surv.ufl.edu/nasa/ - click on "Study Areas").

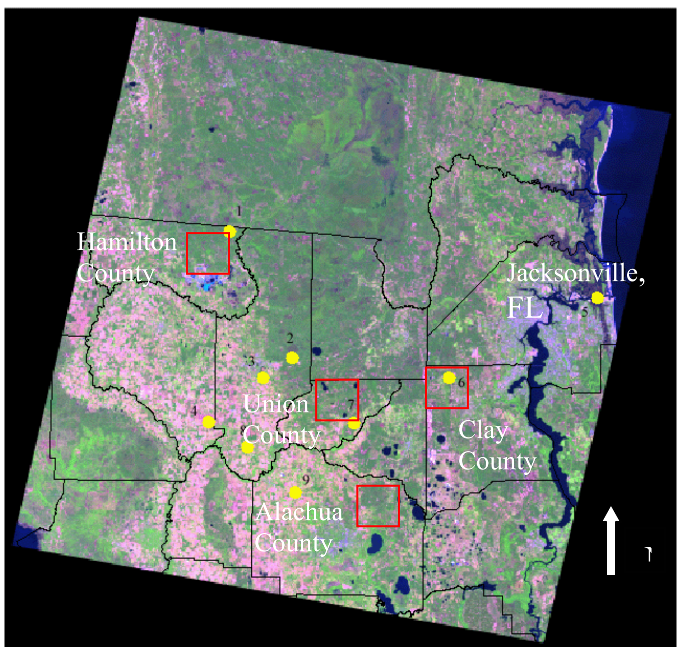



Figure 1. Composite (Bands 5,4, and 3 RGB) image of Landsat WRS 17-39 scene showing random points (yellow dots), and final study areas (red boxes).

The work objectives of this project for the second year's work were, listed under their associated project objectives:

**A. Determine changes in land-cover and land-use patterns in the lower Coastal Plain region from 1975 – 2000, using Landsat MSS and TM data.**

1. To complete the acquisition, pre-processing (subsetting, radiometric and geometric corrections, calculation of various indices), and archiving of all available and appropriate Landsat data for the study area.

2. To create a rational classification system for preliminary work identifying land-cover types that can be linked to known biomass and C measurements from previous work, and to classify study-area subsets of the Landsat scenes.

**B. Determine changes in land ownership/tenure across the same sample areas over the 25-year time period, and linking the ownership patterns with observed land-cover changes.**

1. To complete the acquisition, compilation and reformatting of property maps for four study areas designated in year 1.

2. To acquire and compile land ownership data for each study area.

3. To develop database models that link land ownership with the spatial representation of land boundaries.

**C. Determine changes in the regional C storage over the time period, by estimating the changes in C stored in tree, understory and litter biomass over time resulting from land use changes in the sample areas, based on a synthesis of existing data and ongoing studies on carbon storage in regionally representative ecosystems.**

1. To continue carbon-flux measurements at three eddy-flux tower sites in order to help calibrate the RS-derived estimates of C storage.

2. To generate a look-up table that assigns carbon storage values to different vegetation types characteristic of the S.E. U.S. coastal plain.

3. To develop statistical and index-based models of C content and exchange, using Landsat data as independent variables and existing biomass and C content data as dependent variables, and to extrapolate C content across the landscape by using the models.

4. To compile all available climatological data for the four study areas and for the 25-year period, that will be used as input data to model biomass accumulation and other ecosystem processes.

The status of associated tasks at the end of the second year, are as follows:

**Year 2 Objective A.1.:** Completing the acquisition, pre-processing (subsetting, radiometric and geometric corrections, calculation of various indices), and archiving of all available and appropriate Landsat data for the study area.

During the first year of work (reported April of 2001), we selected four critical times for phenological variation, identified 43 available, cloud-free (in the study areas) Landsat MSS, TM and ETM+ scenes for Row 17, Path 39, and requested 30 scenes to be acquired with the first year's Landsat Data Buy budget. We received 28 scenes of the study area (Table 1). One additional TM and one MSS scenes were already in our possession from other projects.

**Table 1. Landsat Data Inventory 10 April 2002.**
**List includes two scenes acquired earlier.**

| Year | Scene ID | Acquisition Date | Sensor | MSS Data Quality | Notes |
|---|---|---|---|---|---|
| | L7017039000009850 | 04/07/00 | ETM+ | | |
| 2000 | L7017039000000250 | 01/02/00 | ETM+ | | |
| | LT5017039009924710 | 09/04/99 | TM | | |
| 1999 | LT5017039009900710 | 01/07/99 | TM | | |
| 1998 | LT5017039009818010 | 06/29/98 | TM | | |
| | LT5017039009708110 | 03/22/97 | TM | | Had Previously |
| 1997 | LT5017039009727310 | 09/30/97 | TM | | |
| 1996 | LT5017039009615910 | 06/07/96 | TM | | |
| | LT5017039009424910 | 09/06/94 | TM | | |
| 1994 | LT5017039009402510 | 01/25/94 | TM | | |
| | LT5017039009224410 | 08/31/92 | TM | | |
| | LM5017039009224490 | 08/31/92 | MSS | Good | |
| 1992 | LT5017039009202010 | 01/20/92 | TM | | |
| 1991 | LT5017039009101710 | 01/17/91 | TM | | |
| | LT5017039009023810 | 08/26/90 | TM | | |
| 1990 | LT5017039009001410 | 01/14/90 | TM | | |
| 1988 | LT5017039008829710 | 10/23/88 | TM | | |
| | LT5017039008617910 | 06/28/86 | TM | | |
| 1986 | LT5017039008603510 | 02/04/86 | TM | | |
| | LT5017039008415810 | 06/06/84 | TM | | |
| 1984 | LM4017039008400690 | 01/06/84 | MSS | Good | |
| | LT4017039008235210 | 12/18/82 | TM | | |
| | LM4017039008235290 | 12/18/82 | MSS | Excessive Noise | |
| 1982 | LM2018039008202790 | 01/27/82 | MSS | Excessive Noise | |
| | LM2018039008126690 | 09/23/81 | MSS | Good | |
| 1981 | LM2018039008108690 | 03/27/81 | MSS | Good | |
| 1980 | LM3018039008008390 | 03/23/80 | MSS | | |
| 1976 | LM2018039007602390 | 01/23/76 | MSS | Good | |
| 1975 | LM1018039007500190 | 01/01/75 | MSS | Good | |
| 1972 | LM1018039007230590 | 10/13/72 | MSS | Good | |

During the second year's work, we completed preparatory and pre-processing work with the 28 scenes on hand. Sixty ground-control points (GCP) were evenly distributed over the four study areas. Final georectification of the images was completed by the end of November 2001. All scenes were registered to the UTM coordinate system (zone 17N), NAD 83 datum (to correspond with parcel data), and field-checked for accuracy. The September 30, 1997 Landsat TM scene was chosen as the base image for the initial georectification because it exhibited good contrast between vegetation and roads (GCP's were usually taken at road intersections) as well as no cloud cover. Total RMS error for the geometric correction (first-order polynomial with nearest neighbor resampling) was 9.7 m. Subsequent images were registered to the base scene using image-to-image rectification. The average RMS error was 8.0 m for all the images with a maximum value of 8.9 m and a minimum of 6.8 m. Three of the Multi-spectral Scanner images were discarded due to data errors in the delivered data, which consisted of extensive line dropouts, random line offsetting (see Figure 2 and 3), and excessive noise. Consultations with personnel at EROS data center indicated that the original data were corrupt, and that no processing could be performed that would restore the data quality. Geo-corrected images were then subset into the four study regions. NDVI was calculated on each subset. All data are stored in multiple locations, and all team members have copies of all pre-processed satellite data. The intake, processing, and storage of all data have become routine, and the P.I.s and three different graduate students are skilled in the procedures.

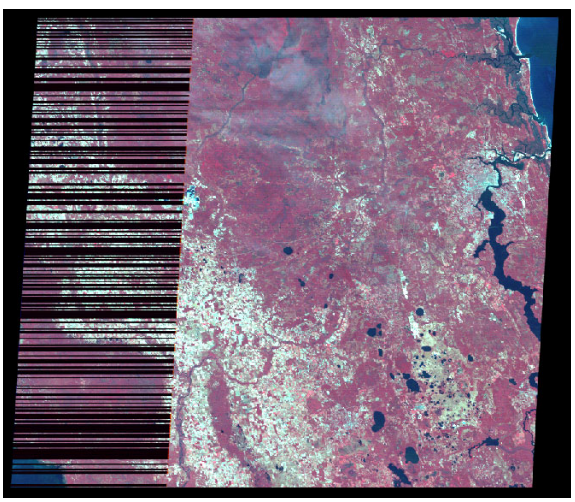


Figure 2. Corrupt MSS scene 23 March 1980.

We were notified in October 2001 that the second-year data buy was forthcoming, and submitted in November to the University of Maryland a list of 24 additional scenes to complete our time-series of appropriate, available data. We received approval on 30 April 2002, so we have not ordered, received, or processed these scenes. Other scenes from appropriate dates, for example 3 October 2001, have been acquired with other funds, and have been added to our data set.

Figure 3a. Detail of 23 March 1980 MSS with random line offsets.

Figure 3b. 1 January 1975 MSS with good data.

**Year 2, Objective A.2.:** To create a rational classification system for preliminary work identifying land-cover types that can be linked to known biomass and C measurements from previous work, and to classify study-area subsets of the Landsat scenes.

We estimate landscape-wide carbon storage with two different approaches. The first uses a look-up table of biomass (= 2x carbon content) for different vegetation classes, based on measurements made by previous and current projects in the study area as well as data from other studies of similar ecosystems. The second method is the use of statistical and empirical approaches such as multiple linear regression, partial least-squares regressions, artificial neural networks, and use of various indices derived from the RS data. This approach was effective in a different vegetation type in the region (Jensen 2000), and evaluating different methods is the subject of Allison Fleming's M.S. thesis, which will be completed during the summer of 2002. We will have much more to report on this approach during the December science team's meeting.

Developing a land-cover classification that makes sense in the context of our study was a challenge because the land-cover classes must both be distinguishable with Landsat MSS, TM, and ETM+ data as well as correspond to vegetation communities for which literature values for biomass or carbon storage exist, and the different studies defined vegetation types in many different ways.

After experimenting with numerous alternatives, the most useful classification is shown in Figure 4. We can discern 4 different growth stages of plantation forests (clear-cut, 1-4 years, 4-8 years, and > 8 years), 2 different categories of forested wetlands or hardwoods (wetland-mixed and cypress), and 3 categories of non-forested land ("urban," agriculture, and open water). Much of the hardwood forest is in urban settings, and we intentionally omit consideration of urban lands in our analysis so the remainder is riparian forest, some of which is wetlands.

To date, 18 scenes have been classified using a supervised classification with these 8 classes. Levent Genc, one of our research assistants, has devised a method to allow common approaches to MSS, TM, and ETM+ data for land-cover classification. In a nutshell, instead of reflectance values used as input data, the first two principle components, the first three tasseled-cap indices, and NDVI are calculated and then used as inputs to the supervised classification. This creates data that are comparable amongst all the different platforms, and classifications that are similar from time to time. Genc is working out the evaluations and other implications of this analysis in his Ph.D. dissertation.

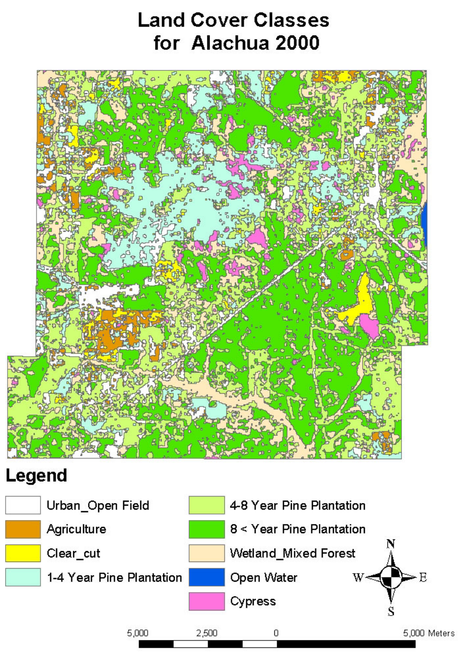



Figure 4. Land cover classification of the Alachua County study area.

We completed one time-step of land-cover change (1995-2000) for the Alachua County study area, and reported it and some analysis at the 2001 meeting of the International Association of Landscape Ecology, North American Chapter. The salient conclusions of that paper were that 1) the landscape suffered an overall loss of biomass (estimated by LAI) due to the onset of a drought in 1998 that continues to today; 2) fire was an important cause of changes of C storage in our study area, and that land owned or leased by commercial institutions was most affected by fire and timber harvest to reduce C storage, but also had the largest areas of regrowth, and hence C uptake; 3) the loss of C was proportional to the total area of the study area owned by commercial institutions, but the gain of biomass C was disproportionately located on the commercial lands, therefore commercial owners can be credited for the greatest C uptake by the vegetation.

**Overall Project Objective B: Determine changes in land ownership/tenure across the same sample areas over the 25-year time period, and linking the ownership patterns with observed land-cover changes.**

**Year 2 Objective B.1:** To complete the acquisition, compilation and reformatting of property maps for four study areas designated in year 1.

While current property information is readily available, historical data for time-series analysis do not exist in easily accessible forms. Property tax appraisers are concerned only with the current property status, so counties maintain and update one single ownership dataset and there is no historical record available. We developed a method for generating temporal data for selected time slices within the last 25 years (e.g. 1975, 1985, 1995, 2000). The method involves tracing parcel changes through the tax parcel number system and identifying private or county entities that have historical parcel records, and is described below.

In the first year of the project we were able to acquire digital land-ownership data for two of our four study sites from the respective County Property Appraiser's Offices. For the Alachua site we obtained parcel and attribute data for years 1995 and 2000, while for Clay County we acquired the same data for year 2000. The data for the other two sites, and the historical data for Clay and Alachua, are all in contained in maps and tax rolls, which are for the most part available only in paper form. We did acquire all the paper records or have easy access at the respective property appraiser's offices.

**Year 2 Objective B.2:** To acquire and compile land ownership data for each study areas,

Because land-ownership data are available, but not spatially referenced in the historic record, we had to develop a method for populating time-series parcel data. We focused on Hamilton County to develop the method instead of the alternative approach of creating four parallel databases for all study sites because the site is the simplest of the four areas in terms of number of parcels (378) and frequency of transactions. Paper maps for the Hamilton County study area were obtained from the County Appraiser's Office and digitized with coordinate geometry and manual digitizing. The database was designed and implemented using MS-Access and the graphics were created using ArcGIS 8.1. The method is now being applied to the other three sites, with completion of the time-series anticipated by early Fall 2002.

Although Hamilton County has a computerized indexing system to track the ownership and taxation history, this index only covers the period since 1990. All other data were extracted manually from annual tax rolls that are compiled in bound volumes. Given the difficulty of extracting every transaction from the appraisal system, and the questionable value of the resulting temporal resolution to the questions being addressed in this research, we established ownership data to a temporal resolution of 5 years. We therefore extracted historical ownership data for 1975, 1980, 1985, 1990, 1995, 2000. These data included name of owner, date of transfer, Public Land Survey System (PLSS) location (township, range and section), deed reference (OR book and page) and the property identification number (PIN) used by the Appraiser's Office. One of the significant problems we had to deal with in this data was that the PIN was not unique, and a unique parcel identifier had to be created.

The PIN used by the Appraisers office can be used to identify more than one parcel at a particular time or it can be retained when a parcel is subdivided as illustrated in Figure 5. Because our basic spatial unit or object is a land-ownership parcel, each parcel must have a unique parcel identifier. If the parcel (object) changes through subdivision or consolidation, new parcels should be given different numbers so that the identifier is unique throughout the period of time being studied. We therefore developed our own unique numbering system by modifying the PIN to incorporate the date that the parcel was created as well as the date it was terminated. The resulting UPI for PIN 1365-000, which was created in 1980 and terminated in 1995, would be:

$$\underbrace{1365\text{-}000}_{\text{PIN}}\ \text{-}\ \underbrace{8095}_{\text{Temporal Suffix}}$$

We limit the time period from 1975 to 2000, so any parcel that was created in 1975 or prior to it was given an initial suffix of 75. Likewise, a parcel that still existed at the end of this period (2000) was given a 01 as the latter part of the suffix. Parcels with a suffix of 00 were assigned to those parcels that were terminated in the year 2000.

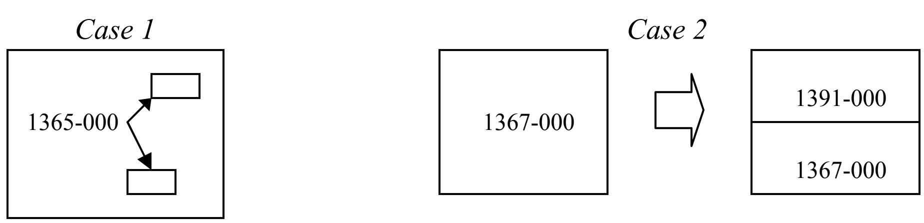



Figure 5. PIN applied to more than one parcel (Case 1) and Retained after subdivision (Case 2)

**Year 2 Objective B.3.:** To develop database models that link land ownership with the spatial representation of land boundaries,

Conventional GIS are not designed to handle spatio-temporal data in an efficient manner that facilitates the kind of space-time analysis inherent to our study. In the first year of the project, we designed a spatio-temporal data model (reported at the end of Year 1) to handle the ownership data in both the spatial and temporal domains. The data model focused on "objects," but was implemented using a conventional relational database. Through the design and implementation of such a model, we could query and track ownership changes and identify trends through the study time period. The database was developed and tested with data from the Alachua County study site over the 1995 – 2000 time period. A paper outlining the development of this model was presented at the Annual Congress of Surveying and Mapping (ACSM) National Conference held in Las Vegas in March of 2001.

This first-draft data model regarded the parcel as the key object within a relational database schema. Every time the object changed either graphically or through a change in ownership, a new object was created. This model was able to track changes efficiently through history by focusing on the attribute data, but it did not address the spatial changes in the parcels. Specifically, it did not allow recreating parcels back through time. This past year we extended the model to solve this problem.

The basic data model is illustrated in the entity-relationship diagram shown in Figure 6.

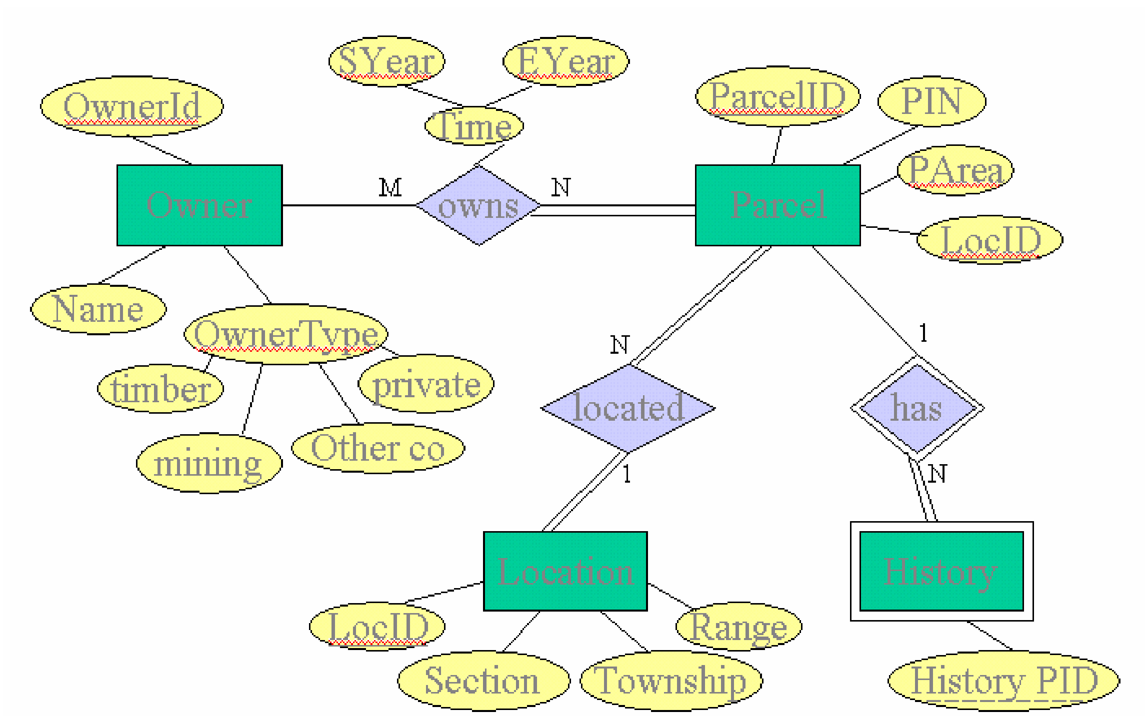



Figure 6. Entity Relationship (E-R) Diagram of Spatio-Temporal Cadastral Database

The database includes owners' names as well as a classification of these owners into categories (e.g. timber companies, mining companies, private owners, etc) which will allow investigation of land use/land cover and carbon changes due to the conversion of ownership from one category to another (e.g. from timber company to private ownership). The history of ownership change is incorporated through including fields for the year (Syear) ownership began and ended (Eyear). The history of change in the cadastral parcel is included in the ParcelID as explained in the previous section.

With the data model designed, we implemented this model by populating the database into specific tables focusing on the definition of parcels, ownership, location and history (the primary entities in the E-R diagram). These tables were related as illustrated in Figure 7.

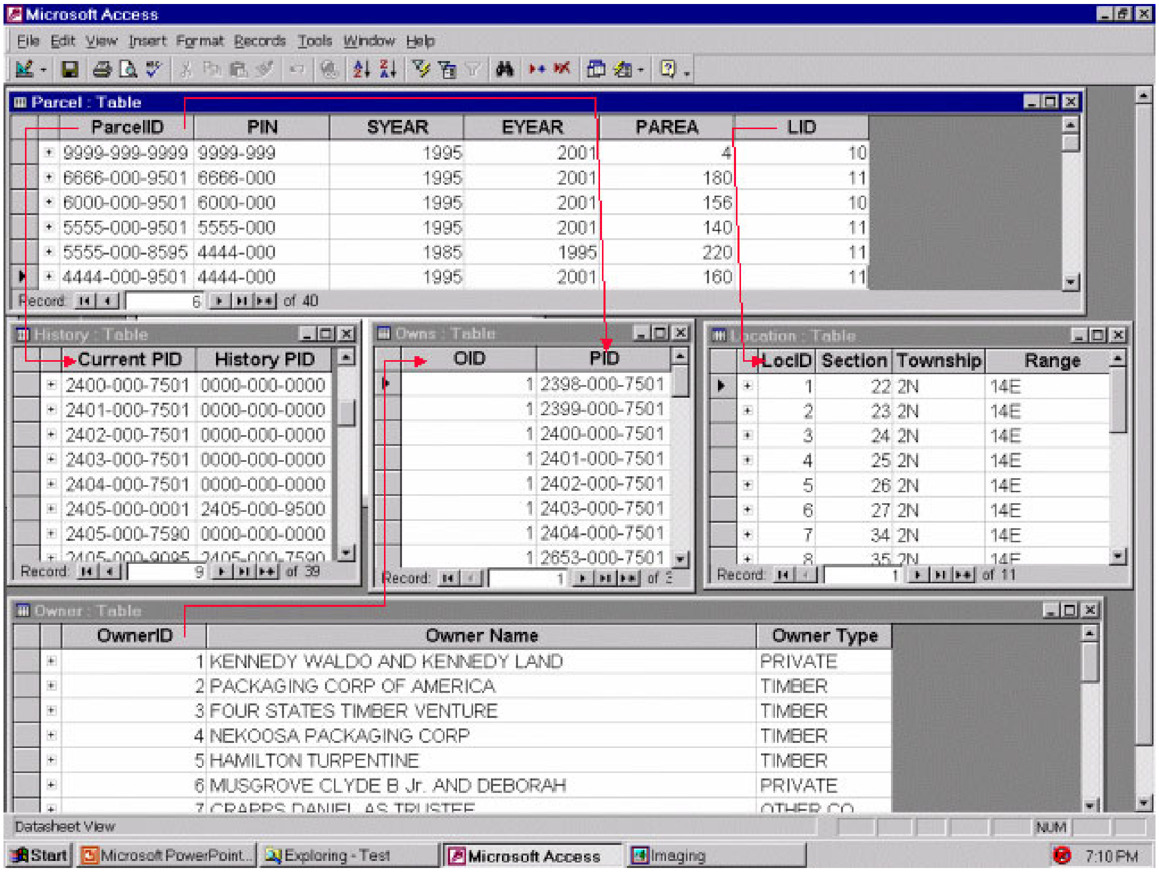



Figure 7. Relational Tables and Linkages between Tables

*Backtracking to Build Historical Cadastral Coverages*

Because the Appraiser's Offices maintain one current tax map of all parcels in the counties in Florida we were able to obtain the current (year 2000) depiction of cadastral parcels for all four sites. In the case of Alachua County we also obtained the tax map for 1995, but other than that no historical cadastral data are maintained by any of the counties incorporating our study areas. We worked back from the cadastral parcels as they existed in year 2000 to obtain cadastral coverages for the other years in which we were interested (1995, 1990, 1985, 1980, 1975). This is akin to examining the children in a family tree and working back to determine their parents, grandparents and other predecessors, with one exception. The analogy holds as long as parcels only change through subdivision (producing children), but in some cases parcels may change through consolidation. In most cases consolidations are not legal events, but standard practice in appraisal offices when two adjoining parcels have the same owner. We identified those cases of consolidation where a boundary may have been deleted on the tax map or where two parcels were given the same parcel identifier because of common ownership. Because these are not legal consolidations (no deed has been submitted to change the legal descriptions of the properties), we either retained the "consolidated" parcels as separate parcels and/or assigned different parcel identifiers to each parcel regardless of the fact that they have a common owner.

The process of backtracking is illustrated in this simple example below (see Figure 8), where in a single section in year 2000 there were 4 parcels. The history table allows us to identify what parcel changes have occurred between any two years.[1] The incorporation of the temporal suffix in our unique parcel identifier system also allows us to identify whether or not a cadastral parcel existed in a specific year.

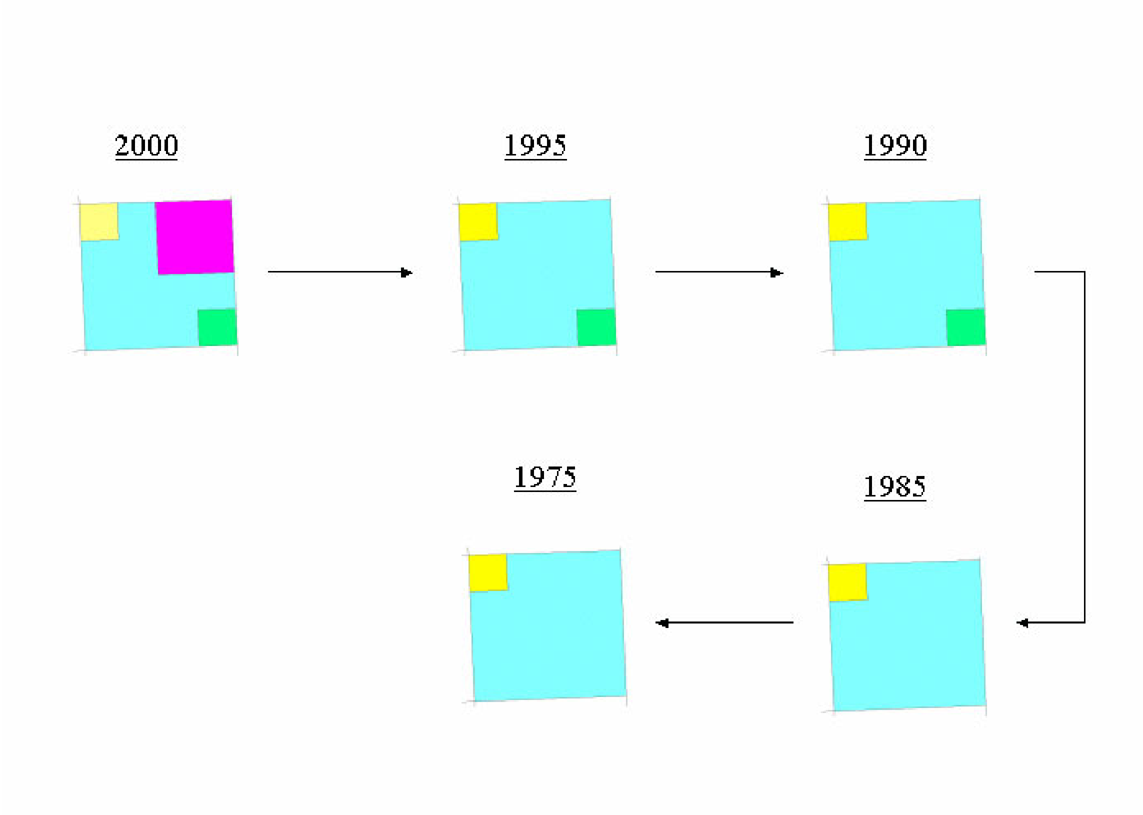



Figure 8. Backtracking to Develop Historical Cadastral Parcel Coverages

Once parcel changes have been identified, the cadastral parcel coverage for a particular year is created by deleting the boundaries that no longer apply. The next task is to automate this final step in the backtracking procedure.

At this stage of the procedure we had (i) a graphic parcel coverage with no associated attributes (except generic polygon attributes created automatically by the software), and (ii) an attribute database in MS Access which contained the linked tables described previously. The UPI was used to link these two sets of data together as illustrated below in Figure 9.

---

[1] Given that the temporal resolution is 5 years, the possible time periods that can be examined are limited to a multiple of 5 years.

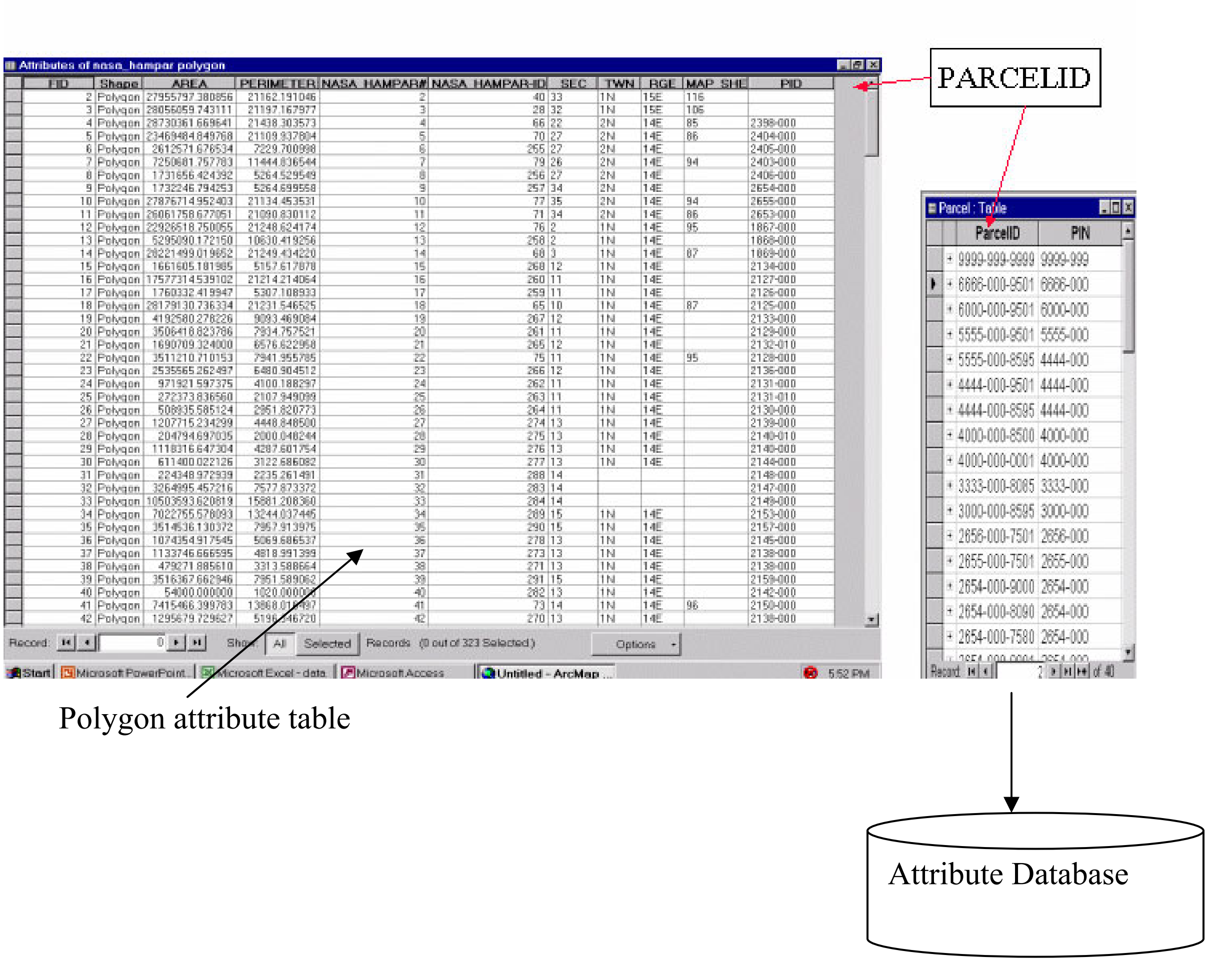
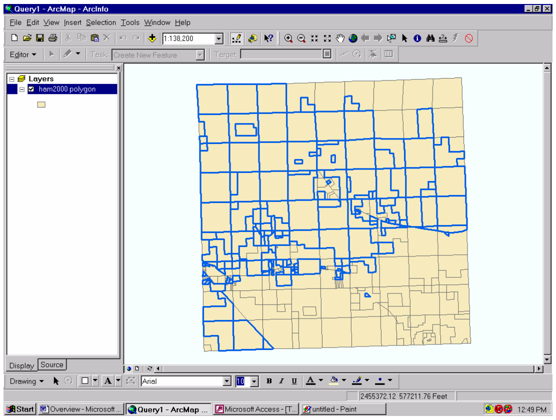



Figure 9. Linking of Attribute Database with Graphic Database

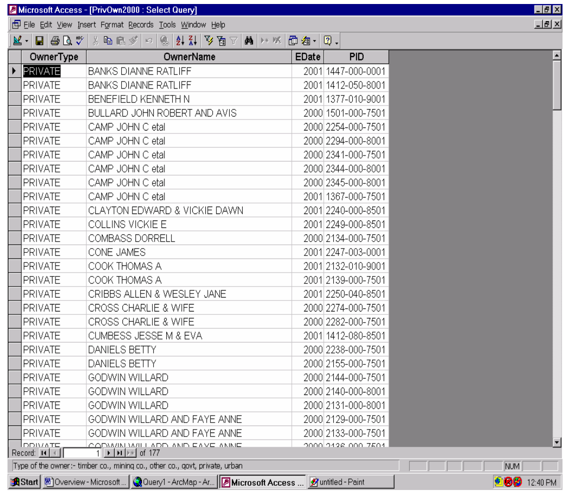
The database was tested by identifying the key queries required in this research and applying them to the database. The queries and results are shown below.

Query 1: Which parcels had private owners in year 2000?

The resulting parcels are shown in blue below in Figure 10a and the associated attributes of these parcels are illustrated in Figure 10b.




A.




| OwnerType | OwnerName | EDate | PID |
|---|---|---|---|
| PRIVATE | BANKS DIANNE RATLIFF | 2001 | 1447-000-0001 |
| PRIVATE | BANKS DIANNE RATLIFF | 2001 | 1412-050-8001 |
| PRIVATE | BENEFIELD KENNETH N | 2001 | 1377-010-9001 |
| PRIVATE | BULLARD JOHN ROBERT AND AVIS | 2000 | 1501-000-7501 |
| PRIVATE | CAMP JOHN C etal | 2000 | 2254-000-7501 |
| PRIVATE | CAMP JOHN C etal | 2000 | 2294-000-8001 |
| PRIVATE | CAMP JOHN C etal | 2000 | 2341-000-7501 |
| PRIVATE | CAMP JOHN C etal | 2000 | 2344-000-8001 |
| PRIVATE | CAMP JOHN C etal | 2000 | 2345-000-8001 |
| PRIVATE | CAMP JOHN C etal | 2001 | 1367-000-7501 |
| PRIVATE | CLAYTON EDWARD & VICKIE DAWN | 2001 | 2240-000-8501 |
| PRIVATE | COLLINS VICKIE E | 2001 | 2249-000-8501 |
| PRIVATE | COMBASS DORRELL | 2000 | 2134-000-7501 |
| PRIVATE | CONE JAMES | 2001 | 2247-003-0001 |
| PRIVATE | COOK THOMAS A | 2001 | 2132-010-9001 |
| PRIVATE | COOK THOMAS A | 2001 | 2139-000-7501 |
| PRIVATE | CRIBBS ALLEN & WESLEY JANE | 2001 | 2250-040-8501 |
| PRIVATE | CROSS CHARLIE & WIFE | 2000 | 2274-000-7501 |
| PRIVATE | CROSS CHARLIE & WIFE | 2000 | 2282-000-7501 |
| PRIVATE | CUMBESS JESSE M & EVA | 2001 | 1412-080-8501 |
| PRIVATE | DANIELS BETTY | 2000 | 2238-000-7501 |
| PRIVATE | DANIELS BETTY | 2000 | 2155-000-7501 |
| PRIVATE | GODWIN WILLARD | 2000 | 2144-000-7501 |
| PRIVATE | GODWIN WILLARD | 2000 | 2140-000-8001 |
| PRIVATE | GODWIN WILLARD | 2000 | 2131-000-8001 |
| PRIVATE | GODWIN WILLARD AND FAYE ANNE | 2000 | 2129-000-7501 |
| PRIVATE | GODWIN WILLARD AND FAYE ANNE | 2000 | 2133-000-7501 |



B..

Figure 10. A. Privately owned parcels in Year 2000 in Hamilton County Study Area. B. Attributes of privately owned parcels in year 2000 in Hamilton County Study Area.

Query 2: What parcels were owned by timber companies in 1990?

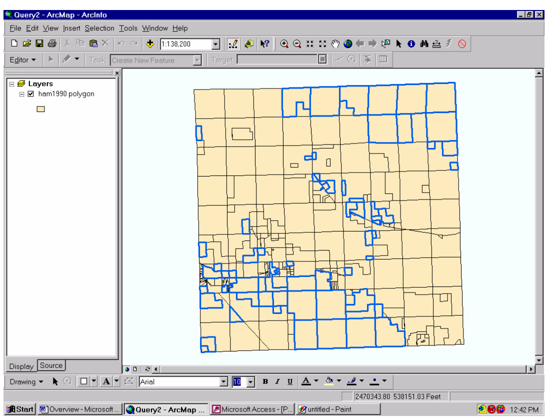
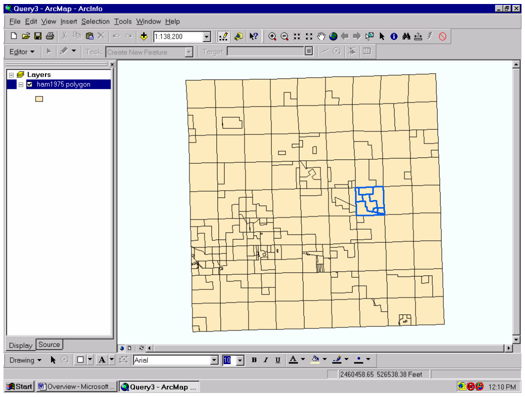



Figure 11. Graphic depiction of parcels owned by timber companies in 1990[2]

---

[2] The accuracy of the categorization of timber companies still needs to be checked and the above should be regarded as illustrative of the query and not an accurate depiction of timber company holdings.

Query 3: List all the parcels and their owner types in Section 10 of Township1N, Range 15E in 1975?



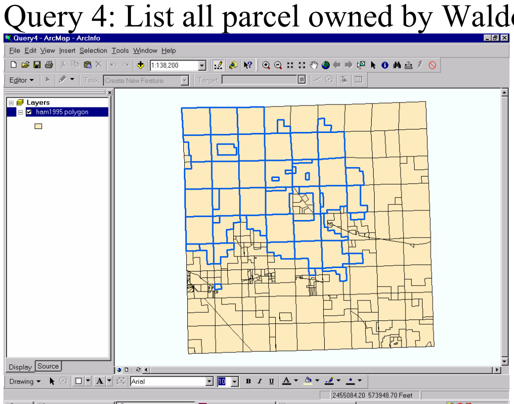
ParOType101N15E75 : Select Query

| ParcelID | OwnerType | Section | Township | Range | SDate |
|---|---|---|---|---|---|
| 1390-000-7501 | MINING | 10 | 1N | 15E | 1975 |
| 1390-001-7501 | MINING | 10 | 1N | 15E | 1975 |
| 1391-000-7501 | PRIVATE | 10 | 1N | 15E | 1975 |
| 1392-000-7585 | PRIVATE | 10 | 1N | 15E | 1975 |
| 1393-000-7500 | PRIVATE | 10 | 1N | 15E | 1975 |
| 1394-000-7501 | OTHER | 10 | 1N | 15E | 1975 |
| 1395-000-7585 | TIMBER | 10 | 1N | 15E | 1975 |

Record: 1 of 7

Figure 12. Parcels and Owner Type located within a specific section of land

Query 4: List all parcel owned by Waldo Kennedy in year 1995?

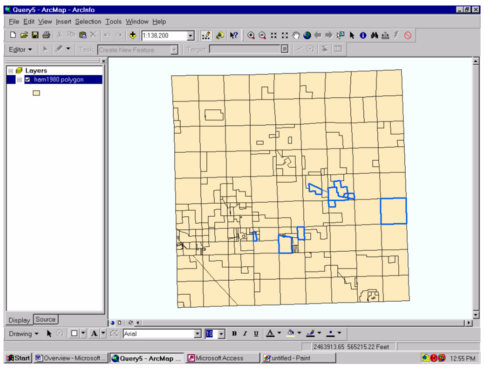


KWaldo1995 : Select Query

| PID | OwnerName | SDate | EDate |
|---|---|---|---|
| 1374-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1380-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1381-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1383-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1389-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1391-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1402-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1404-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1406-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1408-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1866-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1867-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1868-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |
| 1869-000-7501 | KENNEDY WALDO AND KENNEDY LAND | 1975 | 2001 |

Figure 13. Land owned by a specific private landowner in 1995.

Query 5: Which parcels were subdivided between 1980 and 1985?



SubdivP80 : Select Query

| HistoryPID | CurrentPID |
|---|---|
| 1384-000-7585 | 1384-000-8595 |
| 1384-000-7585 | 1384-010-8595 |
| 1392-000-7585 | 1392-000-8500 |
| 1392-000-7585 | 1392-010-8501 |
| 1392-000-7585 | 1392-030-8501 |
| 1395-000-7585 | 1395-000-8501 |
| 1395-000-7585 | 1395-010-8501 |
| 1398-000-7585 | 1398-000-8590 |
| 1398-000-7585 | 1398-010-8501 |
| 1401-000-7585 | 1401-000-8501 |
| 1401-000-7585 | 1401-010-8501 |
| 1412-000-8085 | 1412-000-8501 |
| 1412-000-8085 | 1412-060-8501 |
| 1412-000-8085 | 1412-080-8501 |
| 1416-000-7585 | 1416-000-8595 |
| 1428-000-7585 | 1428-000-8501 |
| 1428-000-7585 | 1428-010-8501 |
| 1428-000-7585 | 1428-020-8501 |
| 1456-000-8085 | 1456-000-8590 |

Figure 14. Parcels that existed in 1980 that were subsequently subdivided between 1980 and 1985.

Query 6: Which parcels were privately owned in 1985 and subsequently transferred to commercial owners (timber, mining, other) between 1985 and 1990?

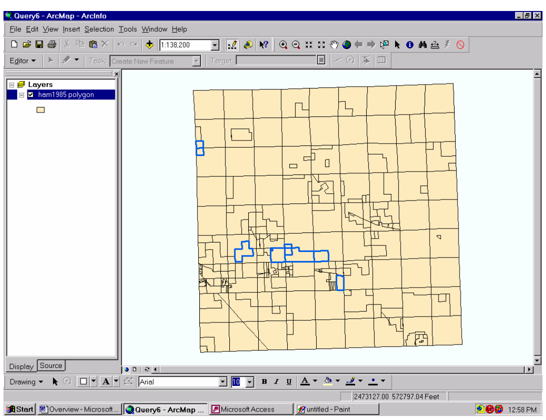


Figure 15. Parcels that were privately owned in 1985 and subsequently transferred to commercial owners between 1985 and 1990?

Query 7: Show all urban parcels (< 5 acres) in year 2000?

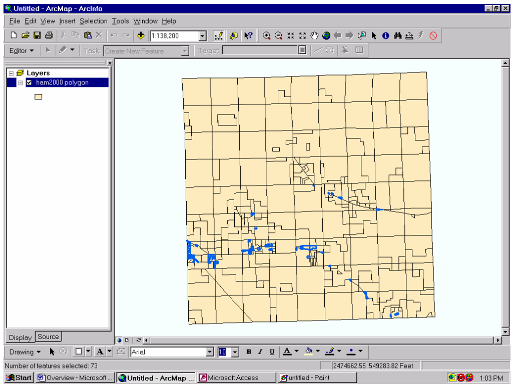


Figure 11. Urban Parcels in year 2000

**Overall Objective C: Determine changes in the regional C storage over the time period, by estimating the changes in C stored in tree, understory and litter biomass over time resulting from land use changes in the sample areas, based on a synthesis of existing data and ongoing studies on carbon storage in regionally representative ecosystems.**

**Year 2 Objective C.1:** To continue carbon-flux measurements at three eddy-flux tower sites (one partially funded by this grant) in order to calibrate the RS-derived estimates of C storage.

The Alachua study area contains an AmeriFlux program site (http://public.ornl.gov/ameriflux/ Participants/Sites/Map/index.cfm). The program conducts direct and long-term measurements of carbon dioxide and water vapor fluxes between terrestrial ecosystems and the atmosphere at 50 sites in North and South America. The north Florida site consists of four eddy-flux measurement towers, three of which are operating now. In addition to the ongoing measurements of net ecosystem exchange at the two other towers not funded by the NASA grant, one tower is located on the Austin Cary Memorial Forest (ACMF), which is a research and teaching forest owned by the University of Florida. Details of standard measurements and general results were described in the Year 1 report.

Approximately half of Florida's terrestrial ecosystems are pine flatwoods, which are comprised of a mixture of two-thirds pine uplands and one-third shallow deciduous wetland depressions. Since the 1960s these flatwoods have been largely converted from open-canopy natural forests to intensively managed slash pine (*Pinus elliottii* var. *elliottii* Engelm.) plantations. Nonetheless, natural and uneven-aged management still comprises about 20% of Florida's timber land (Brown 1995), and is increasingly being considered an alternative silvicultural model on non-industrial forest lands. Yet, how this management strategy influences regional carbon exchange has not been examined. From July 2000 to June 2001, we used eddy covariance to estimate carbon exchanges for an open-canopy, 40-to-70-yr-old, naturally regenerated, mixed slash and longleaf pine (*Pinus palustris* Mill.) flatwoods ecosystem in north central Florida (Austin Cary Memorial Forest, ACMF). These measurements will be combined with those in the managed, industrial pine plantation forests to give a more comprehensive estimate of landscape-wide carbon flux and storage.

The energy budget (latent + sensible + soil energy fluxes vs. net radiation) closure of this system was within 73% ($R^2 = 0.76$). Daytime ecosystem mean maximum net $CO_2$ exchange ($F_c$) for the relatively warmer 110 d period between May 15 and August 31 was –7.6 µmol $CO_2$ $m^{-2}$ $s^{-1}$ at 1500 µmol photosynthetically active photon flux density (PPFD) $m^{-2}$ $s^{-1}$ (negative fluxes indicate transfers from the atmosphere to the forest). Mean maximum daytime $F_c$ for the remainder of the year was significantly greater by 28% ($p < 0.0001$) at -10.5 µmol $CO_2$ $m^{-2}$ $s^{-1}$. $F_c$ was not affected by seasonal differences in leaf-area index (LAI: all-sided LAI was 2.9 in the summer to 2.1 in the winter). Nighttime respiration averaged 4.9 µmol $CO_2$ $m^{-2}$ $s^{-1}$ at 20$^o$ C, with a $Q_{10} = 1.7$ for September, March and June, three months with greater than average precipitation. For the remainder of the year, which was much drier than average, nighttime respiration was 3.7 µmol $CO_2$ $m^{-2}$ $s^{-1}$ at 20$^o$ C and a $Q_{10} = 1.4$. Annual net ecosystem exchange of $CO_2$ was –183 g C $m^{-2}$ $yr^{-1}$.

Direct sampling of biomass provided independent estimates of carbon accumulation that was compared to eddy covariance $CO_2$ flux measurements. Net ecosystem productivity (NEP) can be expressed as:

$$NEP = \Delta B_{trees} + \Delta B_u + \Delta B_{ff} + \Delta B_{soil} = \Delta B_e$$

where change in biomass ($\Delta B$) was estimated for trees, understory, and forest floor, respectively, to yield ecosystem change in biomass and carbon. Soil carbon was assumed to be in steady state, since short-term changes in total soil carbon are not currently possible to detect. For a natural forest ecosystem, this assumption was likely valid since there has been no disturbance to the soil over time (Johnson 1992). Organic matter was assumed to be 50% carbon. Also, litterfall sampling was used to retroactively estimate LAI (Gholz et al. 1991) and establish the amount of carbon assimilated into foliage and added to the forest floor carbon pool for the year (Gholz and Fisher 1982, Gholz et al. 1985). Assuming fine roots and soil organic matter were in steady state, above ground tree biomass, coarse roots and litterfall (Table 2) were summed to yielded annual net ecosystem carbon gain of 236 g C $m^{-2}$ $yr^{-1}$, as compared to 183 g C $m^{-2}$ $yr^{-1}$ measured by eddy covariance. Noting that litterfall totaled 177.0 g C $m^{-2}$ $yr^{-1}$ for March 2000 to February 2001, and at a decomposition rate of 15% per year (Gholz et al. 1985), approximately 157 g C $m^{-2}$ was added to the forest floor storage pool.

Half-hourly $F_c$ during the day for the ACMF was less than that of surrounding plantation ecosystems, but similar to summer rates of a nearby cypress (*Taxodium* spp.) wetland (Table 2). Nighttime $F_c$ was similar between the pine ecosystems and slightly lower for the cypress wetland. The annual NEE estimate for the ACMF stand was considerably lower than NEE estimates for nearby closed canopy slash pine plantations on the same soil type (Table 2,). However, estimates for a nearby clearcut were 1281 and 882 g C $m^{-2}$ $yr^{-1}$ for the first and second years following planting, respectively (Clark et al. in review), indicating that over a plantation management cycle of 20-25 yrs, the average NEEs may be very similar. Mean daily NEE for the ACMF was similar to the mid-rotation aged stand in that neither followed a clear seasonal pattern (Figure 12), which was unlike the rotation-aged plantation and cypress wetland ecosystems studied by Clark et al. (1999, Figure 12). Unlike the rotation-aged stand

and the cypress wetland, the ACMF and mid-rotation aged studies were conducted during a severe drought, implying that carbon sequestration is influenced seasonally by water stress on the ecosystem.

The ACMF understory and forest floor and soil $CO_2$ flux was 35% of the total ecosystem flux. The $CO_2$ flux of the understory in the more naturally managed ecosystem in considerably more important than what has been estimated for nearby plantations (Gholz and Fisher 1982), likely due to the much more open canopy at this site.

Annual C accumulation in stem biomass of trees in the ACMF stand was considerably less than of neighboring even-aged plantations. Nevertheless, this ecosystem showed a net gain of $CO_2$. When considered in the context of the severe drought, this ecosystem should sequester much more carbon during years with more average climatic conditions. At landscape and regional scales, the occurrence of such mature, more natural stands would buffer the large annual fluctuations in NEE that characterize the current pine plantation dominated landscape.

Table 2. ACMF stand characteristics and biomass estimates. This site is an open-canopy, 40-to-70-yr-old, naturally regenerated, mixed slash and longleaf pine (*Pinus palustris* Mill.) flatwoods ecosystem, and is studied because natural and uneven-aged forests comprise about 20% of Florida's timber land (Brown 1995), and are increasingly being considered an alternative silvicultural model on non-industrial forest lands. Data are from Powell (2002).

| | |
|---|---|
| Stand area | 41 ha, 95% pine uplands, 5% cypress wetlands |
| Mean density | $325 \pm 36$ stem $ha^{-1}$* |
| Mean canopy height | $22.1 \pm 0.55$ m |
| Mean canopy dbh, 2001 | $25.7 \pm 1.17$ cm |
| Mean canopy basal area 2001 | $18.0 \pm 0.95$ $m^2$ $ha^{-1}$ |
| Tree biomass for 2001: | |
| Above ground stem and branch tissue (includes bark)[1] | $5750 \pm 650$ g C $m^{-2}$ |
| Foliage[1] | $259 \pm 28$ g C $m^{-2}$ |
| Roots[2] | 747 g C $m^{-2}$ |
| Tree biomass increment: | |
| Above ground stem and branch (includes bark)[1] | $68 \pm 48$ g C $m^{-2}$ $yr^{-1}$ |
| Foliage[1] | $2.2 \pm 2.0$ g C $m^{-2}$ $yr^{-1}$ |

| | |
|---|---|
| Root[2] | 8.8 g C $m^{-2}$ |
| Total litterfall | 177 ± 11.3 g C $m^{-2}$ $yr^{-1}$ |
| LAI canopy all-sided: | summer: 2.9 winter: 2.1 |
| Understory: | |
| Biomass: *Serenoa*, *Ilex* | 140 ± 26.4 g $m^{-2}$, 103.2 ± 15.0 g $m^{-2}$ |
| Herbs, grasses | 2.3 ± 1.8 g $m^{-2}$, 8.4 ± 4.2 g $m^{-2}$ |
| LAI: *Serenoa, Ilex* | 0.65, 0.22 |

* mean ± SE

1. Estimated using allometric equations from Taras and Phillips (1978) for *P. elliottii* and Taras and Clark (1977) for *P. palustris*.

2. Estimated as 13% of aboveground wood (plus bark), Gholz and Fisher 1982.

Table 3. Net CO2 exchange and NEE for ACMF and surrounding ecosystems under contrasting management.

| Forest ecosystem: | Trees $ha^{-1}$ | Canopy LAI summer | Daytime $F_c$ ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$ at 1500 $\mu mol$ PPFD $m^{-2}\ s^{-1}$): | Nighttime $F_c$ at $20^o$ C ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$): | Annual NEE ($g\ C\ m^{-2}\ yr^{-1}$) | Reference: |
|---|---|---|---|---|---|---|
| Pine flatwoods ecosystems: | | | | | | |
| ACMF | 325 | 2.9 | -7.5 to –10.5 | 4 | -183 | this study |
| clearcut plantation (1st yr) | | | -5 | 4 | 1281 | Clark et al. in review |
| mid-rotation plantation | | | -13 | 4 | -575 | Clark et al. in review |
| rotation-aged plantation | 1300 | 6.5 | -14 | 5 | -647 | Clark et al. 1999 |
| cypress wetland (unmanaged) | 2563 | 5.9 | -8 | 3.4 | -84 | Clark et al. 1999 |

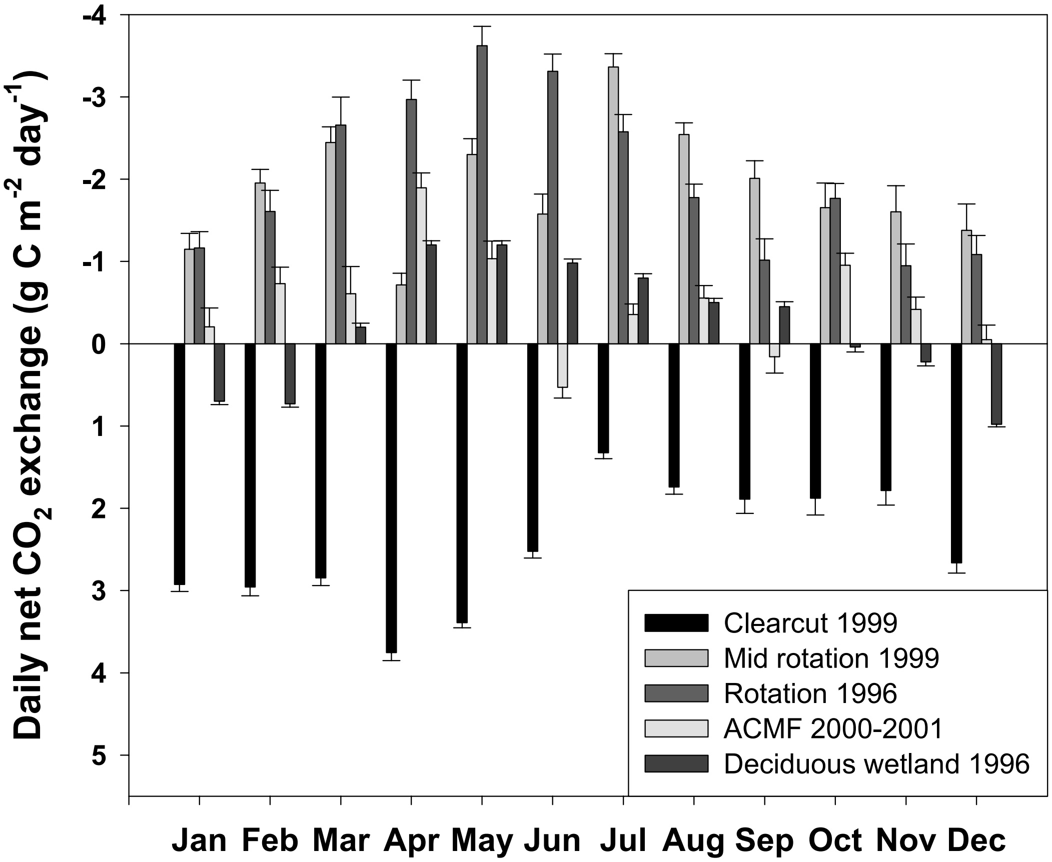



Figure 12. Comparison of mean daily net exchange of carbon (g C $m^{-2}$ $d^{-1}$ ± 1 SE) for contrasting ecosystems and land-uses in the pine flatwoods of north-central Florida.

**<u>Year 2, Objective C.2:</u>** To generate a look-up table that defines carbon storage values in different vegetation types characteristic of the S.E. U.S. coastal plain.

Library research to locate studies of biomass measurements in lowland vegetation of the Southeastern United States for the table was completed in early summer 2001. The table contains 85 entries from 15 different papers or reports for seven different types of forests defined by their dominant tree species (*Pinus elliottii* - Slash Pine, *P. taeda* - Loblolly Pine, *Taxodium distichum* - Bald Cypress, *Liquidambar styraciflua* - Sweetgum {also included several other species of oak, ash, elm, and hickory}, *Populus deltoides* - Cottonwood, *Nyssa aquatica* and *N. sylvatica* – Water and Swamp Tupelo, and *Quercus nigra* – Water Oak). Slash pine and loblolly pine are both upland forest types, while all the rest are mesic hardwoods or bottomland, riparian, or wetland forests. Twenty-one of the entries were from Gholz and Fisher (1982), which was a study in our Alachua County study area of *P. elliottii* biomass along one of the few true chronosequences reported in the literature. Plantation pines included mostly slash pine and loblolly pine, but we include only slash pine in our table because there are no loblolly pine plantations in the study area. The literature reported standing biomass for all management types including natural stands, plantations with and without fertilizers, plantations with different land treatments (disked, thinned and unthinned, etc.), The table entries are summarized by mean and standard deviation, and provided input to the development of the land use classification (reported above). Three categories were chosen representing the dominant vegetation types in the study areas: forested wetland (cypress, and blackgum/water tupelo), riparian (cottonwood, wateroak, and sweetgum), and pine (nearly all slash pine in plantations, but also the "natural regrowth" stand at ACMF). Slash pine plantations were further broken down by age categories 0-4, 4-8, and 8+ years, which can be distinguished by the Landsat land-cover classification. Standard deviations for categories indicate broad ranges of carbon content estimates because of the wide age classes.

Table 4. Biomass (2 x Carbon) Look-up Table for Study Sites.

| **Land-Cover Class** | **Description** | **n** | **Mean (Mg/ha)** | **S.D. (Mg/ha)** | **Range (Mg/ha)** |
|---|---|---|---|---|---|
| Forested Wetland | cypress/ blackgum, water tupelo | 8 | 223.0 | 48.3 | 36.0 - 306.2 |
| Riparian Forest | Cottonwood/water oak/sweetgum | 14 | 155.3 | 87.2 | 39.2-293.0 |
| Slash Pine Plantation | 0-4 years | 3 | 0.2 | 0.0 | 0.20 - 0.29 |
| Slash Pine Plantation | 5-9 years | 9 | 25.1 | 15.7 | 5.2-50.6 |
| Slash Pine Plantation | 10+ years | 18 | 129.4 | 36.9 | 68.75-217.36 |
| "Natural Regrowth" Pine | 40-70 years | 4 | 69.0 | 6.7 | |

Table 5. *Pinus elliottii* biomass in chronosequence.

| **Age (yrs)** | **Biomass (Mg/ha)** | **s.d. (Mg/ha)** |
|---|---|---|
| 2 | 0.25 | 0.04 |
| 5 | 6.71 | 2.50 |
| 7 | 41.13 | 8.49 |
| 8 | 27.48 | 2.66 |
| 14 | 92.18 | 28.78 |
| 18 | 115.13 | 0.77 |
| 26 | 173.26 | 33.30 |
| 34 | 158.33 | 52.57 |

We are currently mapping all clearcuts created from 1975-2000 in the Alachua study area from the satellite data, and creating a vector GIS data layer with clear-cuts designated by polygons with date-cut attributes. By working forward from the date of the clearcut, and most likely date of replanting, we can estimate the age of any single stand that was cut during the 1975-2000 time of the study. This both checks the land-cover classification, and allows us a more accurate estimate of biomass/carbon content. The carbon estimates will cover a large proportion of the land area because most of the area is plantation forest with periodic cutting.

ANTICIPATED PROGRESS – GOALS YEAR 3:

1. To complete acquisition of all identified Landsat data for 1975-2000. This objective was not completed in year 3 because of the delay in the approval process.

2. To generate first-estimate carbon maps for all four study areas for the year 2000. This task is a major part of Allison Fleming's M.S. thesis, which will be completed by the end of the summer 2002.

3. To complete land-cover classification for all time-series data at all sites, and generate first alternative carbon maps based on the classification and biomass look-up table.

4. To complete generation of statistical methods (multiple linear regression, partial least-squares regression, artificial neural networks, spectral vegetation indices, etc.) of analyzing Landsat data to allow reasonable accuracy of biomass/carbon estimation.

5. To apply statistical methods to time-series of radiometrically corrected Landsat data for all study areas to generate the second alternative carbon maps.

6. To complete time-series parcel data for all four study areas at 5-year intervals.
    a. Develop spatio-temporal databases for three other study areas
    b. Develop automated boundary deletion in Backtracking Procedure
    c. Analyze cadastral databases to understand property ownership dynamics
    d. Integrate cadastral database with LU/LC and carbon data and analyze

7. To combine time-series parcel data for all study areas with two time-series carbon maps, and examine changes of C over time as a function of land ownership.

8. To generate BGC/Biome models of carbon uptake and storage to estimate landscape-wide changes given actual climate variation, and to compare with time-series landscape C estimates derived from remote-sensing methods. We have not discussed this objective in the report because work on it is just beginning. We have obtained models created by Peter Thornton of the University of Montana, and are learning how to use them in the spatially explicit context of our study sites. The differences between BGC/Biome results, once the model is calibrated, and our estimates of the effects of land ownership will be attributed to climate variation, allowing us to partition out the two different sources of variation.

9. To write several papers for submission to peer-reviewed journals:

    a. Description of the MSS-TM-ETM+ integration method for land-cover classification (first draft is already completed by L. Genc, and will be presented at the The Third International Remote Sensing of Urban Areas to be held on 11-13 June 2002 in Istanbul, Turkey).

b. Description of the methods and results of determining carbon storage with both look-up tables and statistical methods. M.S. thesis by A. Fleming will form the basis of this paper.

c. Report of the NEE measurements in the "natural regrowth" site at the ACMF (T. Powell M.S. thesis forms the basis of this paper).

REFERENCES:


Brown, M.J. 1995 Forest statistics for Florida, 1995. U.S. Forest Service southern Research Station SRS6.

Clark, K.L., H.L. Gholz, J.B. Moncrieff, F. Cropley, and H.W. Loescher.1999. Environmental controls over net exchanges of carbon dioxide from contrasting Florida ecosystems. Ecol. Appl. 9:936-948.

Clark, K. L., H. L. Gholz, M. S. Castro. Carbon dynamics along a chronosequence of slash pine plantations in N. Florida. In preparation

Gholz, H.L., S.A. Vogel, W.P. Cropper, Jr., K. McKelvey, K.C. Ewel, R.O. Teskey and J.P. Curran. 1991. Dynamics of canopy structure and light interception in *Pinus elliottii* stands, North Florida. Ecol. Monogr. 61: 33-51.

Gholz, H.L. and R.F. Fisher. 1982. Organic matter production and distribution in slash pine (*Pinus elliottii*) plantations. Ecology 63: 1827-1839.

Gholz, H.L., C.S. Perry, W.P. Cropper, Jr., and L.C. Hendry. 1985. Litterfall, decomposition, and nitrogen and phosphorus dynamics in a chronosequences of Slash Pine (*Pinus elliottii*) plantations. Forest Science 31:463-478.

Jensen, R.R. 2000. Measurement, Comparison, and Use of Remotely Derived Leaf Area Index Predictors. Dissertation, University of Florida. 133 pages.

Johnson, D.W., 1992. Effects of forest management on soil carbon storage. Water Air Soil Poll. 64, 83-120.

Powell, T.L. 2002. Carbon, water and energy exchange for a mature, naturally-regenerated pine forest in north-central Florida. M.S. Thesis, Univ. of Florida, Gainesville.

Taras, M. A. and A. Clark, III. 1977. Aboveground biomass of longleaf pine in a natural sawtimber stand in southern Alabama. U. S. Forest Service Southeastern Forest Experiment Station. SE-162.

Taras, M. A. and D. R. Phillips. 1978. Aboveground biomass of slash pine in a natural sawtimber stand in southern Alabama. U. S. Forest Service Southeastern Forest Experiment Station. SE-188.

PRESENTATIONS, PUBLICATIONS, AND REPORTS GENERATED BY THIS PROJECT, 2001-2002.


Anurag. A. “Designing a Spatiotemporal cadastral database to track land ownership history” unpublished M.E. thesis. April 2002 (anticipated)

Binford, M.W., C. Leslie, R. Britts, G. Barnes, H.L. Gholz, S.E. Smith. 2001. Decadal-scale spatial dynamics of land cover, land ownership, land management in industrial and non-industrial forests in the southeastern coastal plain region of the U.S. U.S. Chapter of the International Association of Landscape Ecology Annual Meeting, 25-29 April 2001, Tempe, AZ.

Genc, L. et al**, “**Landsat TM-Based Forest Cover Change Case Study (1990-2000) Alachua County Florida”. The Third International Remote Sensing of Urban Areas to be held on 11-13 June 2002 in Istanbul, Turkey. Abstract and paper accepted.

Genc, L. “New method of Manipulating Landsat MSS and Landsat TM Imaginary for Improvements of Land Cover Accuracy” Doctoral Dissertation, December 2002 (anticipated).

Gholz, H.L. and K.L. Clark. (in press) Water and energy exchange along a chronosequence of slash pine forests in Florida. 2002. Ag. For. Meteorol.

Leslie, C. “An Object-Oriented Approach for Tracking Cadastral Data in the Spatio- Temporal Domain” June 2001. University of Florida, M.E. Thesis, 106p.

Leslie, C., et al, “A Spatio-Temporal Data Model for Analyzing the Relationship between Property Ownership Changes, Land Use/Land Cover and Carbon Dynamics” presented at the 2001 Spring ACSM Conference. Las Vegas.

Powell, T.L. 2002. Carbon, water and energy exchange for a mature, naturally-regenerated pine forest in north-central Florida. M.S. Thesis, Univ. of Florida, Gainesville.

Powell, T.L., G. Starr, T.A. Martin, K.L. Clark and H.L. Gholz. 2001. Net exchange of carbon dioxide, water, and energy for a mature uneven-aged pine flatwoods forest in north Florida. Ecological Society of America Annual Meeting, Madison, WI. (poster)

Powell, T.L., G. Starr, T.A. Martin, K.L. Clark and H.L. Gholz. 2001. Net exchange of carbon dioxide, water, and energy for a mature uneven-aged pine flatwoods forest in north Florida. IUFRO Canopy Conference, Corvallis, OR. (poster)

Smith S. et al. 2001. Progress report to the annual NASA LULC meeting at the University of Maryland, September 2001: “Land-Use and Land-Cover Change: Decadal-Scale Dynamics of Carbon Storage Patterns as a Function of Land Ownership in the Southeastern Lower Coastal Plain Region of the U.S.”

Starr, G., T.L. Powell, T.A. Martin and H.L. Gholz. 2001. An assessment of uneven-aged pine flatwoods in north-central Florida: carbon, water and energy fluxes. Department of Energy, Terrestrial Carbon Program (TCP) Meeting, Chicago, IL. (presentation).

Starr, G., T. L. Powell, T. A. Martin, and H. L. Gholz. Impacts of environmental stress on carbon and water exchange of flatwoods pine forests in Florida. New Mexico State University, April 2002, Las Cruzes, NM.

Starr, G., T. A. Martin, and H. L. Gholz. Weather anomalies and their influences on physiology and fluxes. Department of Energy, Terrestrial Carbon Meeting, AmeriFlux, Chicago, IL, October 2001.

Starr, G., T. A. Martin, K. L. Clark, and H. L. Gholz. The role of extreme events on carbon sequestration of *Pinus elliottii*: Scaling from leaf to ecosystem. Ecological Society of America meeting, August 2001, Madison, WS.

Powell, T. L., G. Starr, T. A. Martin, K. L. Clark, and H. L. Gholz.Net exchange of carbon dioxide, water, and energy for a mature uneven-aged pine flatwoods forest in north Florida. Ecological Society of America meeting, August 2001, Madison, WS.

Thornton, P.E., B.E. Law, H.L. Gholz, K.L. Clark, E. Falge, D.S. Ellsworth, A.H. Goldstein, R.K. Monson, D. Hollinger, K.T. Paw U, J. Chen and J.P. Sparks. 2002. Modeling and measuring the effects of disturbance history and climate on carbon and water budgets in evergreen needleleaf forests. Agric. For. Meteorol. (in press).